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(54) Method and apparatus for controlling drilling operation.

(57) In drilling control method and apparatus for making holes through a composite workpiece (3) made of a plurality of materials (3a, 3b) having different machining properties, the workpiece (3) is first drilled at a feeding speed and a rotational speed of a drill (1) which are selected. When the drilling of the workpiece is initiated, the amounts of the feed speed and the rotational speed are detected by a feed speed sensor (5) and a rotational speed sensor (6), respectively, and thrust force applied to the drill during the drilling is also detected by a thrust sensor (8). The detected feed speed and the rotational speed of the drill (1) are compared in a comparison unit (7) with optimum values which are adapted to the detected thrust force. When the detected values of the feed speed and the rotational speed of the drill coincide substantially with the optimum values, the drilling operation is performed, while when the detected values of the speed do not coincide with the optimum values, the feed speed and rotational speed of the drill are changed to the optimum values.

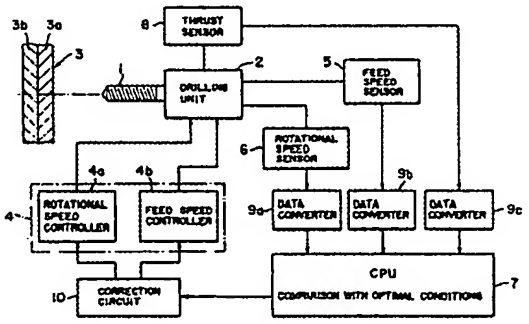

FIG. 1

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METHOD AND APPARATUS FOR CONTROLLING DRILLING OPERATION

BACKGROUND OF THE INVENTION

The present invention relates to a drill control method and apparatus, and, more particularly, to a method and apparatus for controlling drilling operation when holes are drilled through a composite workpiece which is made of a plurality of materials of different machining properties.

Ordinarily, holes are drilled by rotating and feeding a drill at a constant speed. However, in case where holes are drilled through a composite workpiece made of a plurality of laminated materials of different machining properties, a drilling condition adapted to one of the materials may not be proper to another material, and boundary-layer peeling or chipping phenomena tends to occur and thus deteriorates the quality of the drilled holes. In addition, the usable life of the drill becomes short, and selection of the drilling condition is extremely difficult.

In order to eliminate the difficulties described above, there has been developed a drilling control method wherein drilling conditions, such as the feed speed and the rotational speed are set beforehand, which are suitable for each material; each material is drilled constantly under the set condition; the terminating point of drilling of the material is detected from the time required or from an amount of the feed of the drill; the drilling condition is then changed to another one suitable for the material of the next layer; and the drilling operation is carried out continuously by changing the drilling conditions one by one as described above.

For controlling the rotational speed of the drill, there has been proposed a method for controlling the spindle speed for the drill (for instance, refer to Japanese Patent Laid-Open (KOKAI) No. 274843/1986). In this method, a variable speed motor is used for driving the spindle, and this motor is controlled based on a difference between a command speed and an actual speed.

For monitoring the cutting conditions, there has been proposed a device for controlling the machining condition (Japanese Patent Laid-Open (KOKAI) No. 15060/1987). In this device, a load cell is interposed between a chuck and a mounting surface therefor. The load cell detects the thrust force applied to the drill and delivers a voltage corresponding to the thrust. When the voltage exceeds a predetermined value, a terminating point of the drilling operation is detected without requiring any other positioning means.

However, even if the drill feeding speed is controlled according to the method disclosed in Japanese Patent Laid-Open (KOKAI) No. 274843/1986, and the completion of the drilling of one material is determined by the device disclosed in Patent Laid-Open (KOKAI) No. 15060/1987, the process becomes too complicated because drilling conditions of a number equal to that of the materials must be set beforehand, and furthermore the feed speed and the rotational speed of the drill must be varied in accordance with thickness of each material.

In addition, the drilling condition even for the same material must be varied according to the thrust force applied to the drill for preventing the boundary layer from peeling and for improving the quality of the drill hole, and optimum control of the drill is difficult under such conditions. The former method does not provide such operations.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a method and an apparatus for controlling drilling operation, wherein the difficulties of the conventional method are eliminated without using complicated process.

Another object of the invention is to provide a method and an apparatus for controlling the drilling operation wherein setting of drilling conditions for a workpiece made of composite materials is not required, and each material of the workpiece is drilled in dependency on thrust force detected through the operation of drilling the material.

These and other objects of the present invention are achieved by a method of controlling drilling operation, comprising the steps of initiating the drilling operation for a material at a feed speed and a rotational speed of a drill; detecting the feed speed and the rotational speed of the drill and thrust force applied to the drill; and controlling the feed speed and the rotational speed of the drill based on the detected thrust force so as to maintain an optimum drilling condition.

According to the present invention, there is also provided an apparatus, comprising: a feed sensor for detecting a feed speed of a drill; a speed sensor for detecting a rotational speed of the drill; a trust sensor for detecting thrust force applied to the drill while the material is drilled; comparison means for comparing outputs of said sensors with optimum values; correction means for correcting the feeding speed and the rotational speed according to a result of comparison; and control circuit for controlling the feed speed and

the rotational speed of the drill according to an output of the correction means.

A preferred embodiment of the present invention will become understood from the following detailed description referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing an apparatus for controlling drilling operation, according to the present invention; and

FIG. 2 is a flow chart showing steps of a method for controlling drilling operation, according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the block diagram of FIG. 1 showing general arrangement of the apparatus for controlling drilling operation of the present invention, a drill 1 is fixedly mounted on a drilling unit 2. The drill 1 is rotated by the drilling unit 2 and is shiftable toward and away from a workpiece 3, which is a composite workpiece made of a plurality of materials 3a and 3b having different machining properties.

A control device 4 is connected to the drill unit 2 for controlling the rotational speed and the feed speed of the drill 1. The control device 4 comprises a rotational speed controriler 4a and a feed speed controller 4b. A feed speed sensor 5 and a rotational speed sensor 6 are connected to the drill unit 2 for detecting the rotational speed and the feed speed of the drill 1, respectively.

Furthermore, a thrust sensor 8 such as a load cell is coupled to the drill unit 2 for detecting axial thrust force applied to the drill 1 when the drill 1 is forced into the workpiece 3. Outputs of the feed speed sensor 5, the rotational speed sensor 6 and the thrust sensor 8 are supplied to a CPU 7 via data converters 9a, 9b, and 9c, such as A-D converters, respectively. In the CPU 7 is stored or memorized beforehand optimum relations of the values of the thrust force, the feeding speed and the rotational speed of the drill 1 for respective materials of the workpiece. The CPU 7 functions to compare the output data obtained from the sensors 5, 6 and 8 with the optimum relations of the thrust force, the feed speed, and the rotational speed of the drill 1, and delivers an output to a correction circuit 10. The correction circuit 10 corrects the feed speed and the rotational speed depending on the output of the CPU 7, and delivers control signals to the rotational speed controller 4a and the feed speed control 4b of the control device 4. The control device 4 controls the rotational speed and the feed speed of the drill 1 in dependency on the control signals.

FIG. 2 is a flow chart illustrating the method for controlling the drilling operation according to the present invention.

At the start of the control, the thrust force applied to the drill 1 is set to zero before drilling. In a step 1, the rotational speed and the feed speed are set for a first material of the workpiece (condition (A)). In a step 2, thrust force applied to the drill 1 due to the drilling of the first material is detected by the thrust sensor 8. In a step 3, the rotational speed and the feed speed of the drill 1 detected by the sensors 6 and 5 are compared with optimum rotational speed and optimum feed speed (optimum condition (B)) of the drill 1, which are determined in dependency on the detected thrust force. When it is determined in a step 4 that the condition (A) is at least substantially equal to the optimum condition (B), the drilling operation is carried out in a step 6 with the initially set speeds maintained. However, at the step 4 when it is determined that the condition (A) is not substantially equal to the condition (B), the rotational speed and the feed speed are corrected, and the process returns to the step 2 where the thrust force is detected. Then, a cycle (steps 2→3→4→5→2) repeats until the condition (A) becomes close to the condition (B), that is, whether or not an adaptive control is obtained is checked at a setp 7 , and when the result is YES, the drilling operation for the material is terminated at a step 8, while the steps return to the step 2 when the result is NO at the step 4. Thereafter, the drilling operation is carried out in the same manner for a second material of the workpiece.

Although in the method described above, the rotational speed and feed speed are set at the step 1 as the condition (A), it will be apparent that the rotational speed and feed speed set for the previously drilled material may be used for these values.

Further, although the CPU 7 are used for memorizing the optimum conditions and comparing the outputs of the sensors 5, 6 and 8 with the optimum conditions, it will be understood that any other circuit adapted for accomplishing these functions may also be used instead of the CPU 7.

While the presently preferred embodiments of the present invention have been shown and described, it is to be understood that this disclosure is for the purpose of illustration and that various changes and modifications may be made without departing from the scope of the invention as set

forth in the appended claims.

According to the present invention, the optimum drilling operation is performed in the simple method in which the best feed speed and rotational speed for respective materials are taken by detecting the thrust force generated by the drilling operation. Therefore, accuracy and quality of drilled holes are improved and usable life of the drilled becomes long. As it is not required to previously set the drilling condition according to thickness of the materials, the operation becomes easy and fast.

Claims

1. A method of controlling drilling operation, characterized by the steps of:
initiating the drilling operation at a feed speed and a rotational speed of a drill (1);
detecting the feed speed and the rotational speed of the drill (1) and thrust force applied to the drill; and
controlling the feed speed and the rotational speed of the drill based on the detected thrust force so as to maintain an optimum drilling condition with respect to the material.

2. An apparatus for controlling drilling operation of a drilling unit having a drill, characterized in that the apparatus comprises: a sensor (5) for detecting a feed speed of the drill (1);
a sensor (6) for detecting a rotational speed of the drill;
a sensor (8) for detecting a thrust force applied to the drill (1) while the drilling operation is carried out for a material (3);
comparison means (7) for comparing outputs of said sensors (5, 6, 8) with optimum values for said material;
correction means (10) for correcting the feed speed and the rotational speed according to a result of comparison; and
control circuit (4) for controlling the feed speed and the rotational speed of the drill (1) according to an output of the correction means (10).

3. The apparatus according to claim 2 wherein said comparison means is a central processing unit (7) which compares the outputs of said sensors (5, 6, 8) with optimum values memorized beforehand in said means (7).

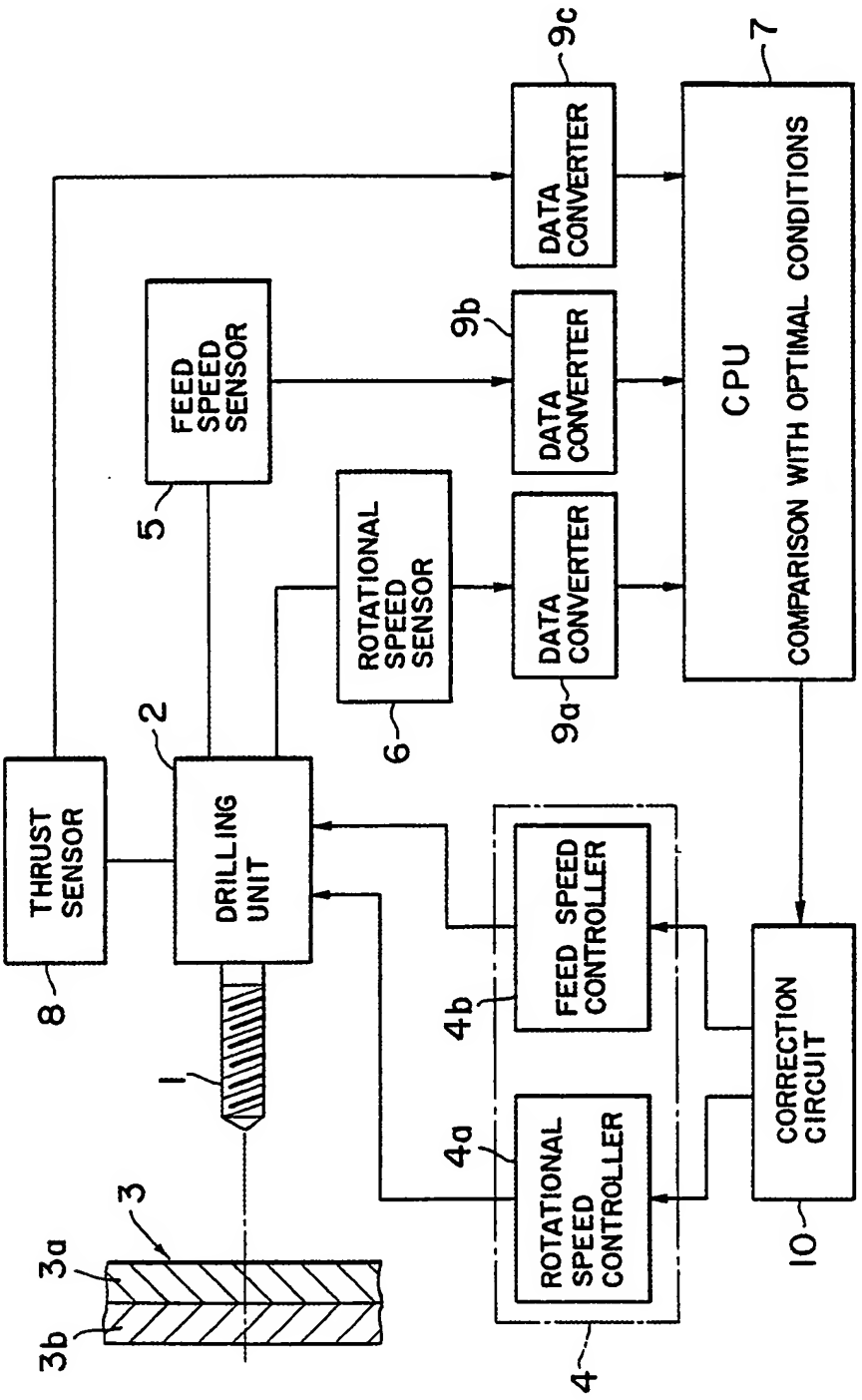
9c
DATA CONVERTER
7
CPU
COMPARISON WITH OPTIMAL CONDITIONS
FEED SPEED SENSOR
9b
DATA CONVERTER
5
ROTATIONAL SPEED SENSOR
DATA CONVERTER
6
9a
2
THRUST SENSOR
DRILLING UNIT
FEED SPEED CONTROLLER
4b
CORRECTION CIRCUIT
8
1
4a
ROTATIONAL SPEED CONTROLLER
10
3
3a
3b
4

FIG. 1

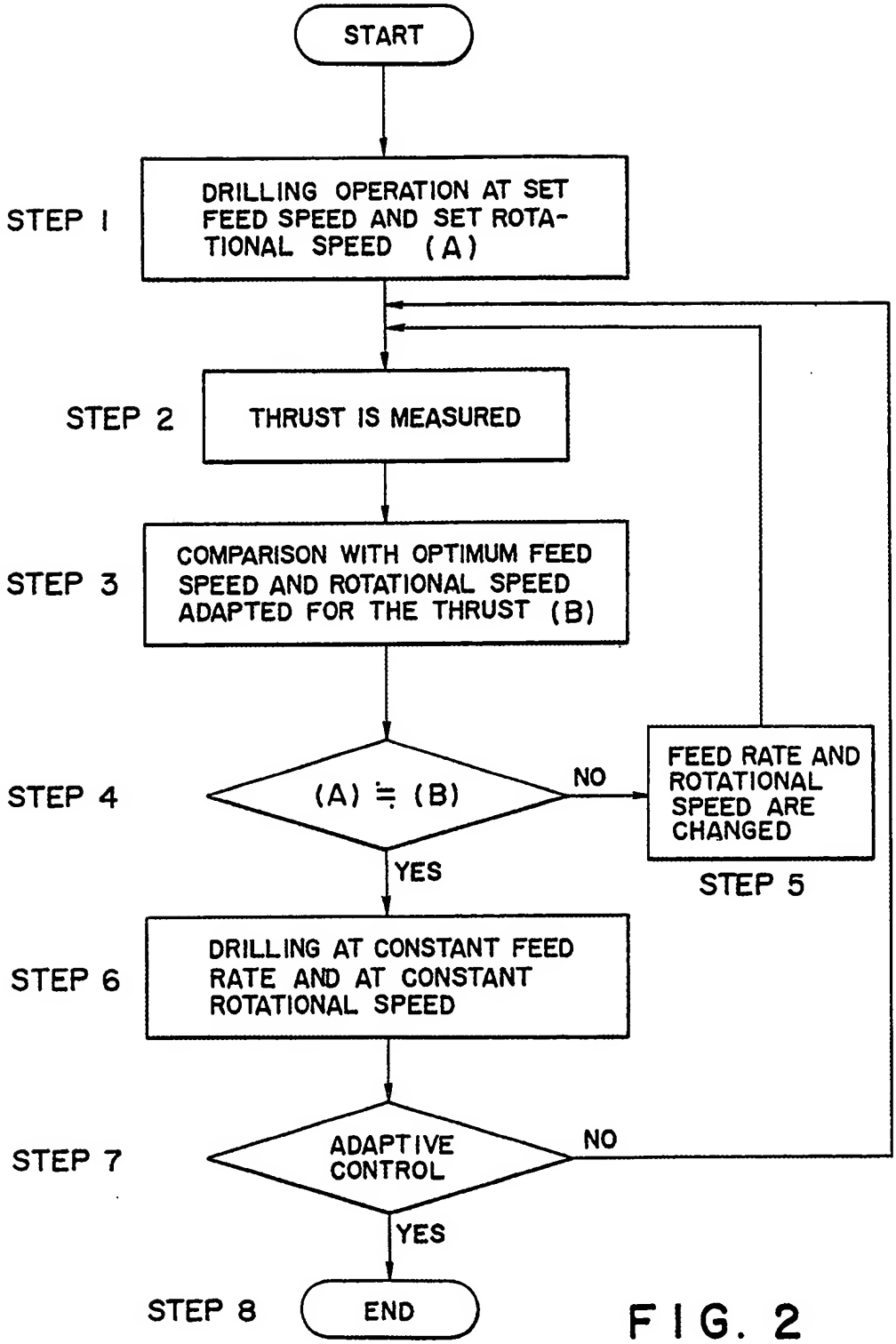
START
STEP 1
DRILLING OPERATION AT SET FEED SPEED AND SET ROTATIONAL SPEED (A)
STEP 2
THRUST IS MEASURED
STEP 3
COMPARISON WITH OPTIMUM FEED SPEED AND ROTATIONAL SPEED ADAPTED FOR THE THRUST (B)
STEP 4
(A) ≒ (B)
NO
FEED RATE AND ROTATIONAL SPEED ARE CHANGED
STEP 5
YES
STEP 6
DRILLING AT CONSTANT FEED RATE AND AT CONSTANT ROTATIONAL SPEED
STEP 7
ADAPTIVE CONTROL
NO
YES
STEP 8
END

FIG. 2